Stroke Care in Low- and Middle-Income Countries: Addressing Disparities and Advancing Equitable Outcomes

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Received: 16th July 2025; 29th July 2025

Abstract

Stroke continues to disproportionately burden low- and middle-income countries (LMICs), where resource scarcity, deeply ingrained cultural beliefs, and systemic weaknesses severely impede effectivecare across the entire continuum. This article critically examines the current landscape of stroke care in LMICs -- -from symptom recognition and prehospital response to acute treatment and long-term rehabilitation. Drawing on the latest Global Burden of Disease (GBD 2021) data [1,2], this report highlights the alarming rise in stroke incidence and associated disability-adjusted life-years (DALYs) in LMICs, a trendstarkly contrasting with improvements in high-income countries (HICs). Key challenges identified include pervasive low public awareness, significant prehospital delays exacerbated by inadequate emergency medical services (EMS) and geographical barriers, limited access to essential diagnostics and life-saving therapies, and a profound deficit in rehabilitation infrastructure and specialized personnel. This work also explores the often-overlooked influence of cultural misattributions of stroke and the substantial socioeconomic burden on informal caregivers. This analysis identifies and analyses innovative, scalable solutions---such as community education initiatives, mobile stroke units (MSUs), drone-based medical delivery, task-shifting models, and telemedicine---demonstrating their potential to bridge critical gaps. By quantifying the economic imperative and proposing actionable policy frameworks, this article underscores the urgent global investment required to achieve stroke care equity and mitigate stroke's devastating human and economic toll in the world's most vulnerable regions.

STROKE CARE, LOW- AND MIDDLE-INCOME COUNTRIES (LMICS), HEALTH DISPARITIES, GLOBAL HEALTH,SYMPTOM RECOGNITION, PREHOSPITAL CARE, ACUTE TREATMENT, REHABILITATION, ECONOMIC BURDEN, POLICY,INNOVATIVE SOLUTIONS, GBD 2021.

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1. Introduction: The Escalating Global Burden of Stroke and Persistent Disparities in Care

Stroke represents a profound and growing global health challenge, particularly within low- and middle-income countries (LMICs). This section establishes the current epidemiological landscape, highlighting the increasing burden and the stark disparities in care that necessitate urgent global attention.

1.1. Global Epidemiology of Stroke: Updated Incidence, Prevalence, Mortality, and DALYs

Stroke remains a leading cause of death and disability worldwide. In 2021, it was the second leading cause of death globally, accounting for approximately 7 million fatalities annually, and the third leading cause of death and disability combined, resulting in over 160 million disability-adjusted life-years (DALYs) lost each year[1]. The absolute number of stroke cases has increased substantially worldwide between 1990 and 2021. Incident strokes rose

by 70%, deaths by 44%, prevalent strokes by 86%, and DALYs by 32%. In 2021 alone, there were 11.9 million new stroke cases and 93.8 million people living with the aftermath of a stroke globally[1,2].

A concerning epidemiological trend reveals a shift towards younger populations being affected by stroke. In 2021, approximately 15% of all strokes (1.76 million cases) occurred in individuals aged 15-49 years,and 53% in those younger than 70 years[4]. This demographic, often in their prime productive years, faces significant health challenges. The impact of stroke on this younger, economically active population has profound socioeconomic consequences beyond direct healthcare costs. It translates to substantial lost productivity, reduced workforce participation, and increased dependency ratios, further entrenching poverty at both household and national levels, especially in economies heavily reliant on a young, active workforce. This makes the economic argument for intervention even stronger and more urgent than previously articulated·

Regarding stroke types, ischemic stroke (IS) constitutes the majority, accounting for 65.3% of incident strokes globally. Intracerebral haemorrhage (ICH) follows at 28.8%, and subarachnoid haemorrhage (SAH) at 5.8%[1]. However, the distribution of stroke types varies significantly by income level. While high-income countries (HICs) exhibit a higher proportion of ischemic strokes (74.9%), LMICs face a significantly higher proportion of intracerebral haemorrhage (ICH) at 31.1% compared to 17.8% in HICs[1]. This higher prevalence of ICH in LMICs fundamentally alters the treatment landscape. ICH management often requires different, often surgical, interventions and meticulous blood pressure control, rather than thrombolysis, which is primarily for ischemic strokes. This means that even if thrombolytics were widely available and affordable, they would only address a smaller proportion of the stroke burden in LMICs compared to HICs. This necessitates a broader approach to acute care infrastructure that includes neurosurgical capabilities and advanced monitoring, not just reperfusion therapies, highlighting a critical mismatch between global HIC-centric treatment guidelines and LMIC epidemiological realities.

The economic burden of stroke is immense, with an estimated global cost exceeding US$890 billion annually, representing 0.66% of the global GDP. This cost is projected to nearly double by 2050[21].

1.2. Disproportionate Burden in Low- and Middle-Income Countries (LMICs): Contrasting Trends with High-Income Countries (HICs)

The majority of the global stroke burden disproportionately affects LMICs, which account for 87.0% of all stroke-related deaths and 89.0% of DALYs[1,2]. This alarming trend stands in stark contrast to the progress observed in HICs. While HICs have achieved a consistent decline in age-standardized stroke incidence and mortality rates over several decades, LMICs have experienced a substantial increase, with incidence rates more than doubling in some regions. The GBD 2021 study revealed a concerning stagnation in the reduction of age-standardized stroke incidence rates from 2015 onward, with some regions, including Southeast Asia, East Asia, Oceania, and countries with lower Sociodemographic Index (SDI), even experiencing increases in stroke incidence, death, prevalence, and DALY rates[1].

This escalating burden in LMICs is attributable to a complex interplay of factors. It reflects a higher prevalence of modifiable risk factors, such as untreated hypertension, which accounts for 56.8% of attributable DALYs, and high body mass index (BMI), which saw an 88.2% increase in attributable DALYs between 1990 and 2021[1]. Beyond these traditional modifiable risk factors, LMICs also face an increasing impact from environmental factors. High ambient temperature, which saw a 72.4% increase in attributable DALYs, and ambient particulate matter pollution, contributing 16.6% of attributable DALYs (and 14.2% for SAH-related DALYs), are emerging as significant contributors to the stroke burden, particularly in regions like North and Central Africa, the Middle East, and South Asia[1]. This reveals a dual challenge for LMICs. In addition to addressing traditional modifiable risk factors, which are often linked to lifestyle transitions, LMICs must also contend with the growing impact of environmental factors. This necessitates a broader public health strategy that integrates climate change adaptation and air quality improvements into stroke prevention efforts, moving beyond individual behavioural

Table 1: Global Stroke Burden (2021) - Key Metrics and Disparities by Income Level

Metric / Category	Global Absolute Numbers (2021)	Proportion in LMICs (2021)	Stroke Type Distribution (Global 2021)	Stroke Type Distribution by Income Level (2021)	Key Modifiable Risk Factors (2021 DALYs Attributable)
Incident Strokes	11.9 million		IS: 65.3%	IS (HICs: 74.9% vs. LMICs: 63.4%)	93% [2]
15-49 years	1.76 million (15%)		ICH: 28.8%	ICH (HICs: 17.8% vs. LMICs: 31.1%)	Ambient Particulate Matter: 16.6%
<70 years	6.3 million (53%)		SAH: 5.8%	SAH (HICs: 7.3% vs. LMICs: 5.5%)	Smoking: 13.7%
Males	6.3 million (53%)				High LDL Cholesterol: 13.1%
Females	5.7 million (47%)				Household Air Pollution: 11.2%
Prevalent Strokes	93.8 million				Diet High in Sodium: 10.6%
15-49 years	20.3 million (22%)				High Fasting Plasma Glucose: 10.3%
<70 years	61.0 million (65%)				High BMI (increase in attributable DALYs): 88.2%
Males	47.8 million (51%)				High Ambient Temperature (increase in attributable DALYs): 72.4%
Females	46.0 million (49%)				
Deaths from Stroke	7.3 million annually	87.0%			
15-49 years	0.37 million (5%)				
<70 years	2.4 million (33%)				
Males	3.8 million (52%)				
Females	3.5 million (48%)				
DALYs	160.5 million annually	89.0%			
15-49 years	21.4 million (13%)				
<70 years	88.1 million (55%)				
Males	88.3 million (55%)				
Females	72.2 million (45%)				
Estimated Global Cost	US$890 billion annually				

**Data sourced from GBD 2021 study.*

changes to systemic environmental interventions. This is a complex, long-term challenge that requires inter-sectoral collaboration beyond healthcare.

1.3. Defining the Landscape: Terminology and Scope of Stroke Care Continuum

For academic precision, this article primarily utilizes the term "low- and middle-income countries (LMICs),"as classified by the World Bank, rather than the historically rooted "third world" label, which loosely describes nations with fragile infrastructure and socioeconomic challenges. The stroke care continuum,the focus of this analysis, encompasses four critical phases: symptom recognition, prehospital care, acute treatment, and post-acute care/rehabilitation. In HICs, rapid recognition, robust emergency systems, and advanced treatments significantly improve patient outcomes. Conversely, patients in LMICs encounter formidable barriers at every stage of this continuum, which collectively amplify stroke's devastating human and economic toll[8],[9].

1.4. Article Structure and Objectives

This article traces the patient's journey through the stroke care continuum in LMICs, meticulously dissecting the challenges encountered at each phase. It contrasts these realities with standards in HICs, highlighting critical disparities. The overarching objective is to inform global health strategies and inspire actionable, scalable solutions aimed at mitigating stroke's devastating impact in vulnerable regions and advancing equitable stroke care worldwide.

2. Critical Gaps in the Stroke Care Continuum in LMICs

This section delves into the specific barriers encountered at each stage of stroke care in LMICs, providing detailed evidence and highlighting the compounding effects of these challenges.

2.1. Pre-Hospital Phase: Awareness, Recognition, and Cultural Determinants

The initial moments following stroke onset are critical, as "time is brain" underscores the urgency of rapid intervention. In high-income countries (HICs), public health campaigns like FAST (Face, Arms, Speech,Time) have significantly enhanced symptom recognition, often leading to hospital arrival within an hour of symptom onset. However, in LMICs, this crucial lifeline is frequently absent or ineffective.

Public awareness of stroke symptoms is profoundly low. A 2018 study in rural Ghana, for instance, found that only 11% of respondents could identify common stroke signs, with a significant proportion of survivors (43%) initially seeking care from herbalists rather than medical facilities[9]. Similarly, studies in India indicate substantial prehospital delays, often around 12 hours, primarily due to poor recognition of early stroke symptoms and a limited understanding of the dangers associated with delayed hospital arrival[9]. In Pakistan, delays are further compounded by limited public and referring doctor awareness regarding the narrow therapeutic window for thrombolytic therapy[9]. Even in instances where public awareness campaigns exist, health-seeking behaviour can be heterogeneous; a study in Tanzania observed that high knowledge of stroke risk did not consistently translate into immediate and appropriate emergency actions[9].

Cultural beliefs and traditional practices profoundly influence care-seeking patterns in many LMIC settings. In sub-Saharan Africa, stroke is frequently misattributed to supernatural causes, such as witchcraft or divine punishment, leading to significant delays in seeking conventional medical intervention[9]. In India's tribal regions, misdiagnoses attributing stroke symptoms to "evil spirits" are common, delaying action by days. A 2020 survey in Nigeria revealed that 38% of stroke-affected families consulted spiritual leaders before medical facilities, thereby missing the critical 4.5-hour window for thrombolysis[9]. These cultural beliefs, including the assumption that strokes are caused by spiritual reasons or divine retribution, significantly influence healthcare-seeking patterns, often leading patients to seek herbal or traditional treatments, or even combine them with

hospital care, which can limit follow-up after discharge. For example, 25% of individuals in Ghana believed stroke was a spiritual disease, leading them to prioritize spiritual solutions. In Bolivia, half of stroke patients do not seek hospital care due to similar beliefs[10]. These beliefs also extend to rehabilitation, with families in rural Tanzania reportedly abandoning therapy when immediate gains are not observed, expecting a quicker recovery[10].

Geographical barriers and limited communication infrastructure further exacerbate prehospital delays. In remote regions like Ethiopia's highlands, patients may reside 50 kilometres from the nearest clinic, lacking access to phones or paved roads, and relying on rudimentary transport like a neighbour's cart[9]. Rural residence is consistently associated with lower utilization of critical stroke care interventions, including brain imaging and specialist consultations[12]. Patients in rural areas often experience longer delays due to limited access to healthcare facilities and a greater reliance on traditional treatments or general practitioners before seeking specialized medical care. In Bangladesh, for instance, rural patients frequently made initial contact with a general practitioner or village doctor and relied on public transportation to reach hospitals, leading to significant delays[9]. Poor transportation infrastructure, including unpaved roads, further extends travel times, making it challenging to reach medical facilities within critical time frames. The Nepal Stroke Project (NSP) identified that a low level of knowledge about stroke contributed to the under-utilization of health services and prehospital delay, despite the project's efforts to improve communication infrastructure through online and offline public awareness campaigns[13],[14].

The delays in stroke care are not solely attributable to physical distance to a clinic but also to cognitive distance (lack of awareness of symptoms, therapeutic windows) and cultural distance (misattribution to supernatural causes, preference for traditional healers). Even when awareness exists, appropriate action is not always guaranteed, as observed in Tanzania. This implies that simply building more clinics or roads is insufficient. Effective prehospital interventions must address the cognitive and cultural pathways to care. This requires culturally sensitive education campaigns, engagement with traditional healers, and community-level interventions that build trust and shift health-seeking behaviours before the patient needs an ambulance. The "time is brain" concept is rendered meaningless if the initial decision to seek medical help is delayed by hours or days due to these non-physical barriers. Furthermore, these factors are often interconnected. Rural populations in LMICs are frequently poorer, possess lower health literacy, and face greater financial hurdles for transport. Women, particularly in rural settings, may encounter additional cultural or economic barriers to accessing care, as evidenced by lower recruitment and poorer outcomes for women in family-led rehabilitation trials in India[10]. This creates a compounding disadvantage, where multiple layers of vulnerability intersect to produce significantly poorer stroke outcomes. Policy interventions must adopt an intersectional lens, recognizing that solutions for rural areas need to address poverty, education, and gender-specific barriers simultaneously to be truly effective.

2.2. Emergency Response and Transport Challenges

Once stroke symptoms are recognised, rapid transport and stabilization are paramount. In HICs, sophisticated emergency medical services (EMS) with trained paramedics arrive within minutes, stabilising patients en-route to specialized stroke-ready hospitals. This standard of care is rarely mirrored in LMICs.

Formal EMS systems are largely inadequate or non-existent in many LMICs. Guinea, for example, has ambulance access for only 10% of its population. Sierra Leone highlights an extreme disparity, with just 0.02 ambulances serving every 100,000 people, compared to 50 ambulances per 100,000 in the U.S.[9]. Many LMICs lack an organized EMS system, with existing ambulances often serving merely as transport vehicles rather than providing emergency care[5]. The complete absence of emergency ambulance services in some LMICs, such as Somalia, significantly contributes to critical delays in reaching medical facilities[9].

Economic barriers further impede timely transport. In the Philippines, a substantial two-thirds of healthcare costs are out-of-pocket, creating a significant deterrent for families to seek ambulance transport [9]. In Uganda, a stroke

patient's family might resort to selling livestock to afford a taxi, only to then contend with unpaved roads that double travel time[9]. Financial concerns are a major impediment in Nepal, often leading patients to delay seeking care until their illness becomes severe and unavoidable[13]. The high perceived cost of acute stroke treatment, including transport, often shifts the focus of health systems and families towards prevention strategies rather than investing in rapid acute care interventions[17].

Beyond vehicle scarcity, a critical lack of trained prehospital personnel and standardized protocols plagues LMICs. Where paramedics exist, they frequently lack stroke-specific training. There is a demonstrable knowledge gap in stroke management among health professionals, particularly EMS personnel, which directly contributes to prehospital delays[16]. Many LMICs operate with fragmented health systems that lack organized stroke service programs or clear referral protocols. This often results in patients being admitted to basic clinics first, only to be referred to appropriate facilities when their condition deteriorates, as observed in Ghana and the Philippines[9]. Consequently, the "golden hour" for stroke intervention is routinely missed; while 80% of stroke patients in HICs reach care within three hours, this figure drops to below 20% in LMICs[40].

The severe deficiencies in EMS, transport, and trained personnel in LMICs consistently identify the prehospital phase as a critical obstacle to successful treatment. This "prehospital bottleneck" is a primary driver of health disparity, meaning that even if advanced hospital care were available, patients often would not reach it in time or in a stable condition. Therefore, investing in strengthening the prehospital phase – through basic emergency care training, community first responders, and reliable transport – could yield a higher return on investment in DALYs averted than solely focusing on high-tech hospital interventions, especially given the "time is brain" principle. This re-prioritization of foundational emergency care is a crucial strategic shift for LMICs.

2.3. Acute Hospital Care Deficiencies

Acute stroke care demands speed and precision, yet LMICs face profound limitations in providing timely and effective interventions. For ischemic strokes, administering tissue plasminogen activator (tPA) within 4.5 hours is critical for dissolving clots, but this requires accurate diagnosis through imaging to distinguish it from haemorrhagic stroke. In HICs, approximately 90% of hospitals offer CT scans for this purpose. However, in LMICs, such diagnostic tools are often considered luxuries. Guinea, for example, possesses only one CT scanner across its three national hospitals, serving a population of 13 million people[9]. In rural Pakistan, a staggering 80% of district hospitals lack imaging capabilities, forcing medical personnel to make "blind treatment guesses"[9]. Globally, there is less than one CT scanner per million inhabitants in LMICs, a stark contrast to 40 per million in HICs, with even wider disparities for MRI machines[19]. The challenges extend beyond mere equipment acquisition, encompassing the need for specific physical spaces, stable power supply, regular maintenance, and future upgrades, all of which are formidable obstacles in LMICs[18].

The scarcity and exorbitant cost of life-saving thrombolytic therapies further exacerbate the crisis. A single dose of tPA costs approximately $2,000, which is ten times the annual income of an Ethiopian farmer[9]. Although recombinant tPA (rtPA) was added to the WHO Model List of Essential Medicines in 2019, its utilization rate remains suboptimal in LMICs. While HICs boast significantly higher per capita GDP and health expenditure, the median price of rtPA is non-significantly higher in LMICs ($755) compared to HICs ($600). Crucially, in LMICs, the cost of rtPA accounts for an astounding 217.4% of purchasing power parity (PPP)-adjusted per capita health expenditure, in stark contrast to just 17.6% in HICs, rendering it disproportionately unaffordable[20]. This high cost is widely hypothesized to be a major contributor to the low administration rates of thrombolytics in eligible patients.

A critical shortage of stroke specialists and an undertrained healthcare workforce compound these issues. Nigeria, for instance, has only one neurologist per 4 million people, compared to one per 40,000 in the U.S.[9]. General practitioners, often lacking specialized training in stroke protocols, are frequently tasked with managing complex cases, which inevitably leads to higher error rates. The insufficient capacity of health systems in LMICs to manage

Table 2: Summary of Key Challenges in Stroke Care in LMICs with Illustrative Examples

Phase of Care	Key Challenge	Specific Evidence/Example	Broader Implication/Consequence
Pre-Hospital	Low Public Awareness & Delayed Recognition	Only 11% awareness of stroke signs in rural Ghana. Prehospital delays of ~12 hours in India due to poor symptom recognition.	Missed therapeutic windows for acute intervention; increased mortality/ disability.
	Cultural Misattributions	38% of Nigerian families consulted spiritual leaders before hospitals. Stroke blamed on witchcraft/divine punishment in sub-Saharan Africa.	Significant delays in seeking medical care; reliance on ineffective traditional treatments.
	Geographical Barriers & Poor Communication	Patients 50km from clinics in Ethiopian highlands, lacking phones/roads. Rural residence linked to lower use of imaging/ specialists.	Prolonged travel times; limited access to timely diagnosis and treatment.
Emergency Response	Inadequate Formal EMS & Transport	0.02 ambulances per 100,000 people in Sierra Leone vs. 50 in U.S. Many LMICs lack organized EMS, ambulances for transport only.	Missed "golden hour" for intervention; higher disability/mortality rates.
	Economic Barriers to Transport	2/3 of healthcare costs out-of-pocket in Philippines. Families sell livestock for taxis in Uganda.	Deterrence from seeking timely transport; delayed care until severe illness.
	Lack of Trained Prehospital Personnel	Paramedics often lack stroke-specific training. Knowledge gap among EMS personnel.	Unstable patient transit; suboptimal prehospital management.
Acute Hospital Care	Limited Access to Diagnostic Imaging	Only 1 CT scanner per 13 million people in Guinea. <1 CT scanner per million inhabitants in LMICs vs. 40 in HICs.	"Blind treatment guesses"; misdiagnosis; inability to differentiate stroke types for appropriate therapy.
	Scarcity & Affordability of Thrombolytics	tPA costs $2,000 (10x Ethiopian farmer's annual income). rtPA cost is 217.4% of PPP-adjusted per capita HE in LMICs vs. 17.6% in HICs.	Low administration rates of life-saving therapies; disproportionate financial burden.
	Critical Shortage of Specialists	1 neurologist per 4 million people in Nigeria vs. 1 per 40,000 in U.S. General practitioners manage complex stroke cases.	Increased error rates; suboptimal patient management; higher mortality.
Post-Acute Care & Rehabilitation	Insufficient Rehab Infrastructure & Workforce	Only 15.8% of Philippine hospitals have rehab units. 1 physiotherapist per 1.3 million people in Bangladesh.	Limited access to crucial recovery services; prolonged disability.
	Cultural & Health Literacy Barriers	60% rehab dropout in rural Tanzania due to expectation of quick recovery. 45% of Nigerian caregivers didn't understand stroke's chronic nature.	Therapy abandonment; poor adherence; suboptimal functional recovery.
	Socioeconomic Burden on Caregivers	80% of Indian stroke survivors rely on family, pushing 30% below poverty line.	Household impoverishment; exacer- bation of poverty; perpetuation of disadvantage.

neuro-critical care patients necessitates significant capital and human resource investments. The Nepal Stroke Project similarly highlighted the severe scarcity, noting approximately one neurologist per one million people[13].

Challenges of misdiagnosis and pronounced urban-rural disparities further worsen acute treatment outcomes. A study in Uganda found that 25% of stroke cases were initially misdiagnosed and treated as malaria[9]. In Malawi, a 2019 audit revealed that 56% of intracerebral haemorrhage patients died within a week, a rate triple that of HICs, primarily due to delayed surgery and inadequate monitoring[9]. Urban-rural divides mean that while private hospitals in major cities like Nairobi may offer tPA, rural clinics often lack even basic essential drugs[9].

The high cost of tPA in LMICs, which can exceed 200% of per capita health expenditure, presents a critical economic dilemma. While tPA is considered cost-effective in HICs, its relative cost in LMICs makes it a disproportionately

expensive intervention. Macroeconomic models suggest that stroke prevention is more cost-effective than acute treatment for cardiovascular conditions in LMICs[17]. This creates a significant policy challenge: while acute treatment saves lives, the opportunity cost in LMICs may be too high, potentially diverting scarce resources from more broadly impactful and cost-effective preventive measures or basic emergency care. This suggests that LMICs might need to prioritize foundational health system strengthening and prevention strategies before, or in parallel with, widespread adoption of high-cost, time-sensitive acute interventions like tPA, unless significant subsidies or innovative funding models (e.g., flexible pricing from manufacturers) can drastically alter the cost-effectiveness equation. This challenges the direct transferability of HIC treatment paradigms.

2.4. Post-Acute Care and Rehabilitation Bottlenecks

Rehabilitation is a cornerstone of stroke recovery, capable of halving stroke-related disability and restoring independence. However, in LMICs, this vital lifeline is severely compromised.

Insufficient rehabilitation infrastructure and a critical shortage of specialized workforce are pervasive issues. In the Philippines, only 15.8% of hospitals possess rehabilitation units, and these are predominantly located in urban centres, leaving rural survivors without access[10]. Bangladesh exemplifies the extreme scarcity of personnel, with a single physiotherapist serving 1.3 million people, a stark contrast to one per 10,000 in HICs[10]. LMICs generally lack rehabilitation staff, particularly those with specialized training in stroke recovery. Existing facilities are few, concentrated in urban areas, under-funded, and poorly equipped[22]. Furthermore, rehabilitation guidelines developed in HICs are often difficult to implement in LMICs due to fundamental resource scarcity[23].

Cultural and health literacy barriers significantly impede rehabilitation adherence. In rural Tanzania, families often expect a rapid recovery, leading to abandonment of therapy when immediate gains are not observed, with 60% dropping out within a month[11]. Low health literacy is widespread; a 2022 Nigerian study found that 45% of caregivers did not comprehend the chronic nature of stroke[24]. Cultural beliefs, spiritualism, superstition, and social stigma actively hinder engagement with evidence-based rehabilitation, often leading to a preference for herbal and alternative medicines[10]. Gender disparities are also evident, with fewer women recruited to rehabilitation trials in India and those who are, showing poorer outcomes, suggesting additional cultural or societal barriers to engagement[10]. A general lack of awareness about the long-term benefits of rehabilitation is reported in countries like India and Brazil[10]. Personal factors, including apathy towards rehabilitation, a lack of confidence in performing exercises independently, and prioritizing other family or economic roles over therapy, further contribute to poor adherence[10].

The socioeconomic burden on informal caregivers is immense and largely unacknowledged. In India, a staggering 80% of stroke survivors rely on family members for care, which often drains household income and pushes approximately 30% of these families below the poverty line[10]. Untrained relatives bear the brunt of care, struggling to manage complex motor or speech deficits without adequate support. Stroke disables 60% of survivors in LMICs, severely curtailing their workforce participation and imposing vast economic ripple effects across communities[10].

The heavy reliance on family caregivers in LMICs, coupled with the immense, often unquantified, burden they face, points to a hidden epidemic of caregiver strain that exacerbates poverty and perpetuates cycles of disadvantage. The economic impact is substantial, with studies quantifying millions of DALYs and productivity losses associated with informal caregiving[25]. This highlights a critical gap in policy and funding: formal support systems for caregiver – such as training, financial aid, and respite care – are not merely a social welfare issue but a crucial economic and public health intervention for improving long-term stroke outcomes and preventing household impoverishment. Without addressing caregiver needs, the effectiveness and sustainability of rehabilitation efforts will remain severely compromised.

3. Innovative Strategies and Scalable Solutions for Stroke Care in LMICs

Despite the formidable challenges, innovative and scalable solutions are emerging that offer significant potential for improving stroke care in resource-constrained settings. These strategies emphasize adaptation to local contexts and leveraging existing community structures and technological advancements.

3.1. Enhancing Public Awareness and Early Action

Effective community education campaigns and tailored messaging are fundamental to improving early stroke recognition and promoting timely care-seeking. Campaigns utilizing mass media, such as television and newspapers, and specifically targeting stroke survivors, their families, and even children,can significantly increase awareness of stroke symptoms and the critical importance of a rapid response. For optimal impact, messages must be simple, repetitive, and disseminated in accessible locations, including places of worship and waiting rooms. The Nepal Stroke Project (NSP) demonstrated the power of digital platforms, with its social media campaign reaching millions of individuals, showcasing the potential for widespread awareness dissemination[13]. Research indicates that well-designed awareness campaigns can be highly effective in improving knowledge, attitudes, and behaviours, leading to more rapid emergency admissions and, consequently, a reduction in stroke-related mortality[27].

The role of Community Health Workers (CHWs) in early identification and first aid is proving to be transformative. CHWs serve as trusted liaisons between healthcare providers and under served populations, uniquely positioning them for effective emergency response. They are adept at disseminating accurate health information, countering misinformation, assisting vulnerable populations with emergency preparedness, coordinating care between community members and healthcare providers, and identifying and addressing unmet health and social needs during and after crises[28]. CHWs can be effectively trained for cardiovascular disease prevention and management, even those with limited formal education[29]. Their training often incorporates interactive methods and content adapted to local cultures and languages, making it more accessible and impactful. These workers can provide essential outreach, measure blood pressure, and offer crucial lifestyle counselling[30]. Formalizing their role and providing specific training in areas such as mental health first aid and disaster triage would significantly maximize their impact[28].

Instead of solely focusing on expensive, top-down healthcare infrastructure, LMICs can significantly strengthen their stroke care continuum by investing in and formalizing CHW programs. This represents a"bottom-up" approach to health system reinforcement, leveraging existing community trust and local knowledge. CHWs can serve as the first line of defence in stroke recognition, basic first aid, and referral, effectively shortening prehospital delays and improving outcomes at a fraction of the cost of traditional EMS expansion. This requires sustainable funding, standardized training, and integration into national health frameworks, moving beyond short-term, grant-based funding.

3.2. Strengthening Prehospital and Emergency Response Systems

Innovative approaches are crucial for bolstering prehospital and emergency response systems in LMICs. Mobile Stroke Units (MSUs) represent a significant advancement, bringing diagnostic tools such as CTs canners and point-of-care laboratories, along with medical experts, directly to the patient. This expedites diagnosis and treatment, including thrombolysis, within the critical "golden hour"[31],[32]. Studies in HICs, including Germany and Houston, have consistently demonstrated that MSUs improve time metrics, cost-effectiveness, and patient outcomes compared to traditional EMS[31]. In LMICs, a preliminary study by Cherian et al. in India reported the first utilization of an MSU, which was associated with higher thrombolysis rates and improved timeline metrics[33]. However, the widespread implementation of MSUs in LMICs faces challenges such as local regulations, the need for vehicles suitable for rural terrain, high costs (especially for privately run units), and a lack of public and health worker awareness. Currently, there is very limited data regarding their contextual suitability or cost-effectiveness specifically within LMICs[34],[35].

Drone delivery for medical supplies offers a promising solution to overcome geographical and infrastructural barriers. Uncrewed aerial vehicles (UAVs) can drastically reduce delivery times for medications, vaccines, and emergency supplies, particularly in remote areas or during emergencies, by bypassing ground traffic and geographical restrictions[36]. Key innovations supporting drone success include Artificial Intelligence (AI) for autonomous navigation, advanced battery technology for extended flight ranges, and cold-chain capabilities for transporting sensitive products like blood[36]. Case studies from Africa demonstrate significant impact: Rwanda's national health system has integrated Zip line drones, delivering over 35% of the country's blood supply, and Ghana's drone program has improved access to over 150 essential medicines for 12 million patients. In India, Apollo Hospitals has initiated 10-minute drone deliveries of diagnostic samples[36],[37]. Despite these successes, challenges persist, including regulatory uncertainty, maintaining drug stability during flight, high operational costs, and a shortage of trained personnel[36].

LMICs should strategically invest in and adapt disruptive technologies like drones, rather than solely attempting to replicate HIC-style EMS systems. Drones, in particular, offer a cost-effective, rapid, and scalable solution for addressing geographical barriers and supply chain weaknesses, especially for time-sensitive medications or diagnostic samples. This "leapfrogging" approach can bypass decades of traditional infrastructure development, provided regulatory frameworks and local training for operation and maintenance are prioritized. The success of drone programs in Rwanda and Ghana suggests a paradigm shift in emergency logistics for LMICs.

Leveraging Community First Responders (CFRs) and task-shifting models in emergency settings can further strengthen prehospital response. CFRs are volunteers with basic health training who support ambulance services, particularly in rural areas, by providing immediate care and arriving quickly at emergency scenes. In the UK, CFRs attended a significantly higher proportion of urgent calls in rural areas and for neurological/endocrine conditions[38],[39]. Task-shifting, which involves delegating tasks from physicians to less-trained health workers (e.g., nurses, CHWs), is a cost-effective strategy to address workforce shortages in LMICs[41],[42]. The "Stroke 1-2-0 Identification Rule" in China, which trains general practitioners to identify stroke symptoms early, has significantly shortened prehospital delays and increased thrombolytic therapy rates[40]. Addressing transport infrastructure gaps requires systemic change, including increasing the number of vehicles, training staff, and improving road networks. The Dhulikhel Hospital Emergency Medical Services (DEMS) program in Nepal demonstrated that implementing a hotline, dispatch protocol, and training for dispatchers and ambulance staff can cost-effectively improve prehospital care[40].

3.3. Expanding Access to Acute Stroke Treatment

Expanding access to acute stroke treatment in LMICs requires innovative strategies, particularly for diagnostic imaging, affordable medications, and specialist consultation.

Improving diagnostic imaging access and affordability is paramount. While CT and MRI are standard in HICs, portable transcranial ultrasound offers a cheaper alternative for early diagnosis, though it requires trained experts. Radiologists are actively exploring alternatives to deliver high-quality imaging in LMICs, such as utilizing ultrasound as a "fit for purpose" modality due to its portability, solar-power compatibility, long battery life, and user-friendly interface[18]. Innovative care delivery models like "Screen and Refer"or "Hub-and-Spoke," where rural providers capture scans for remote review, and "Imaging Package" approaches that combine technology with training, telehealth, and supervision, are being explored. Point-of-care imaging is crucial to circumvent the need for patients to travel long distances to imaging facilities. It is critical to recognize that solutions from developed countries cannot simply be "copied and pasted"but must be adapted to local contexts and resource realities[18].

Addressing the cost and availability of thrombolytics and other essential medications is a significant challenge. Concerted global efforts are necessary to improve the affordability of rtPA in low-income settings, given its disproportionate cost burden in LMICs[20]. The use of Tenecteplase, a potentially more affordable alternative to rtPA, is highlighted as a cost-effective treatment option.

Furthermore, innovative funding models are urgently needed to bridge the financial gap for high-cost chronic non-communicable disease (NCD) treatments in LMICs. These models can involve unlocking new funding sources or deploying funds directly to patients, leveraging strategic partnerships, multi-donor pooling, sales-linked donations, and charity-funded medical initiatives[43],[44]. Government-initiated methods such as compulsory medical savings accounts, lottery-based funding, sin taxes, and compassionate use models can also enhance financial protection for patients. Technology-enabled crowd-based platforms, including crowdfunding and cryptocurrency, have emerged as novel funding sources[43],[44].

The transformative role of telemedicine and teleneurology is critical in overcoming specialist shortages. Telemedicine connects hospital teams and patients with neurologists in real-time, enabling emergency stroke evaluations, inpatient consultations, and collaborative treatment planning, particularly in underserved areas. This approach improves access, enhances patient retention, and reduces unnecessary transfers, thereby keeping treatment local and timely[45]. Tele-stroke services have been shown to double the administration rate of life-saving thrombolytic therapy and significantly shorten "door-to-needle" times, leading to improved patient outcomes and a reduced long-term economic burden[46],[47].While challenges such as limited internet connectivity, regulatory barriers, and infrastructure deficiencies persist, mobile health solutions and international collaborations are actively working to overcome these obstacles[45],[46].

Telemedicine is not merely a convenience but a critical force multiplier for LMICs grappling with severe specialist shortages. It democratizes access to expertise, enabling timely diagnoses and treatment decisions that would otherwise be impossible. This means LMICs should prioritize investment in robust, reliable telecommunication networks and comprehensive training for local healthcare providers to effectively utilize these platforms. The challenge shifts from having enough neurologists to effectively connecting existing neurologists to the points of need, thereby optimizing scarce human resources.

3.4. Advancing Post-Acute Care and Rehabilitation

Advancing post-acute care and rehabilitation in LMICs requires integrated, context-specific models that address infrastructure, workforce, cultural beliefs, and caregiver support.

Community-Based Rehabilitation (CBR) is a cornerstone strategy. Endorsed by the WHO and other international organizations, CBR aims to promote the inclusion of people with disabilities in LMICs by training local volunteers and caregivers to provide rehabilitation, which effectively cuts costs and boosts adherence[48],[49]. Evidence suggests that CBR can be effective in improving clinical outcomes, functioning, and quality of life for individuals with disabilities and their caregivers [48]. Low-cost physical rehabilitation interventions requiring minimal resources have demonstrated their ability to improve functional outcomes after stroke in LMICs[23]. However, the current coverage of CBR remains very low,and more rigorous evidence on its effectiveness and scalability is needed to fully harness its potential[48].

Tele-rehabilitation presents a significant opportunity for remote support. This approach links rural patients to urban therapists via mobile applications, offering continuity of treatment and addressing challenges such as limited resources, difficult transportation, or long distances to rehabilitation centres. Tele-rehabilitation can stimulate patient motivation and engagement through interactive technologies, robotic devices, or computer games[50]. It holds particular promise for stroke patients in LMICs where specialized expertise or resources may not reach remote areas. Nevertheless, challenges persist, including limitations in internet access, patient acceptability, motivation, engagement, and digital literacy. Further research is crucial to establish its feasibility and effectiveness in diverse LMIC contexts[50].

Formalizing support systems for caregivers is imperative, given the heavy reliance on family members for post-stroke care. In India, for instance, 80% of stroke survivors depend on family caregivers[10]. Formal support should include comprehensive training for caregivers on the chronic nature of stroke and effective rehabilitation techniques,

Table 3: Overview of Innovative Solutions for Stroke Care in LMICs: Evidence and Implementation Considerations

Solution Category	Specific Innovation	Key Evidence/Example	Implementation Considerations/Challenges in LMICs	Potential Impact
Public Awareness	Community Health Workers (CHWs)	CHWs effectively trained for CVD prevention/management. Disseminate health info, assist preparedness.	Need for sustainable funding, standardized training, integration into national frameworks.	Reduced prehospital delays; improved early identification; cost-effective outreach.
	Tailored Education Campaigns	Nepal Stroke Project's social media reached millions. Campaigns improve knowledge, attitude, behaviour.	Messages must be simple, repetitive, culturally sensitive; require sustained funding.	Increased symptom recognition; faster care-seeking; reduced mortality.
Prehospital Response	Mobile Stroke Units (MSUs)	India pilot showed higher thrombolysis rates, improved timelines. MSUs improve time metrics, cost-effectiveness in HICs.	High cost, local regulations, vehicle suitability for rural terrain, limited LMIC data on cost-effectiveness.	Expedited diagnosis & treatment within "golden hour"; improved outcomes.
	Drone Delivery for Medical Supplies	Rwanda: 35% of blood supply delivered by drones. Ghana: access to 150 essential medicines for 12M patients.	Regulatory uncertainty, drug stability during flight, high operational costs, trained personnel shortage.	Rapid delivery of time-sensitive medications/samples; bypasses poor infrastructure; increased accessibility.
	Community First Responders (CFRs)	CFRs in UK attended more urgent calls in rural areas. Task-shifting is cost-effective for workforce shortages.	Requires basic training, volunteer networks, integration with formal EMS.	Quicker initial response; basic first aid; improved patient stability before ambulance arrival.
Acute Care	Portable Diagnostic Imaging	Ultrasound as "fit for purpose" modality (portable, solar powered). "Screen and Refer" models for remote review.	Requires trained personnel; adaptation to local context; overcoming procurement/maintenance issues.	Earlier, more accurate diagnosis; reduced need for patient travel; targeted treatment.
	Innovative Funding Models	Leverage strategic partnerships, multi-donor pooling, sin taxes, crowdfunding.	Need for government stability, clear regulatory policy, local stakeholder partnerships.	Improved affordability of high-cost therapies; increased access to essential medications.
	Telemedicine / Teleneurology	Doubles thrombolysis administration shortens "door-to-needle" times. Connects patients to neurologists in real-time.	Limited internet connectivity, regulatory barriers, digital literacy, infrastructure deficiencies.	Force multiplier for scarce specialists; reduced transfers; timely expert consultation.
Rehabilitation	Community-Based Rehabilitation (CBR)	WHO-backed CBR trains local volunteers, cuts costs, boosts adherence. Improves clinical outcomes, functioning, QoL.	Low current coverage; need more evidence on effectiveness/scalability; local contextualization.	Cost-effective, culturally appropriate long-term recovery; increased adherence.
	Tele-rehabilitation	Links rural patients to urban therapists via mobile apps. Offers continuity of treatment.	Internet access limits, patient acceptability, motivation, digital literacy.	Remote support for therapy; overcomes geographical barriers; continuity of care.
	Formal Caregiver Support Systems	Addressing caregiver burden can prevent household impoverishment.	Requires training for caregivers, financial/psychological support, policy recognition.	Reduced household income drain; improved long-term patient outcomes; enhanced quality of life for families.

along with potential financial or psychological support. Addressing the immense burden on caregivers can mitigate household income drain and prevent families from falling below the poverty line.

A "one-size-fits-all" rehabilitation model from HICs is often ineffective in LMICs due to the complex interplay of infrastructure, workforce shortages, prevailing cultural beliefs, and the immense caregiver burden. The solution lies in developing integrated, context-specific models that blend formal (albeit limited) services with informal (family-based) care, while strategically leveraging community resources (CBR) and technology (tele-rehabilitation). This requires substantial investment in training all levels of care providers, from specialists to family members, developing culturally appropriate rehabilitation protocols, and creating sustainable funding mechanisms that acknowledge and support the critical role of informal caregivers. The focus must be on maximizing functional recovery within the realities of limited resources and prevailing cultural norms, rather than simply replicating Western rehabilitation centres.

4. The Economic Imperative and Policy Frameworks for Stroke Care Equity

The burden of stroke in LMICs extends far beyond clinical outcomes, imposing a severe economic strain that demands strategic policy interventions and sustainable investment.

4.1. Quantifying the Economic Burden of Stroke in LMICs: DALYs, Productivity Loss, and Catastrophic Expenditure

The global cost of stroke is staggering, exceeding US$890 billion annually, a figure projected to nearly double by 2050[21]. LMICs bear the overwhelming majority of this burden, accounting for 89.0% of all DALYs lost due to stroke[1,2]. Stroke is a leading cause of disability and premature mortality, resulting in enormous societal and financial costs associated with long-term care, rehabilitation, and lost productivity.

A multi-country study across Argentina, China, India, and Tanzania revealed that over 50% of stroke patients experienced catastrophic health spending, defined as out-of-pocket health expenditures exceeding 40% of their non-food annual income[26]. This was coupled with significant decreases in productivity post-stroke. In India, direct medical costs constituted two-thirds of total stroke medical expenses, with the remaining third comprising societal costs such as caregiver expenses and lost productivity[26]. The economic burden on informal caregivers is immense and often unquantified, with studies demonstrating substantial losses in quality-adjusted life years (QALYs) and productivity-adjusted life years (PALYs) due to the provision of informal care for stroke patients. For instance, one study estimated a loss of AU$19.1 billion over 30 years from caregiver burden[25].

The overall economic burden of non-communicable diseases (NCDs), including stroke, is projected to reach over US30 trillion in the next two decades, threatening to push millions into poverty. Mental health conditions alone are expected to contribute an additional US16.[1] trillion in losses over the same period[21]. Stroke in LMICs is not merely a health crisis but a major driver of poverty and economic instability at both micro (household) and macro (national) levels. The high out-of-pocket costs and loss of productive years, affecting both patients and their caregivers, create a vicious cycle that traps families in poverty and hinders national development. This reframes stroke as a critical development issue, not just a medical one, demanding investment from finance ministries and development agencies, not solely health ministries. Policies focused on financial protection and social safety nets for stroke-affected families are as crucial as medical interventions.

4.2. Cost-Effectiveness of Interventions: Prioritizing Prevention, Acute Care, and Rehabilitation

Stroke is highly preventable, with a remarkable 84% of the stroke burden in 2021 attributable to 23 modifiable risk factors[1]. Macroeconomic modelling studies consistently suggest that stroke prevention interventions are more cost-effective than acute treatment interventions in LMICs. For example, preventive measures implemented in Mexico were found to be highly cost-effective, averting significantly more DALYs than acute care interventions[17].

The World Health Organization (WHO) generally recommends interventions costing less than three times the annual GDP or GNI per capita as "cost-effective." By this standard, thrombolytics for acute stroke treatment, given their high relative cost in LMICs, may not be considered a cost-effective investment for low-income countries. In fact, basic emergency care training, costing $30-$89 USD per life year saved, and basic paediatric emergency care training and triage, at $165 USD per death averted, appear to be more cost-effective than acute stroke treatment in LMICs[17]. There is a critical need for local data to inform context-specific decisions on cost-effectiveness, particularly given the heterogeneous epidemiology of stroke, including higher rates of haemorrhagic stroke, across different LMIC settings. Furthermore, evidence from Thailand suggests that home-based rehabilitation for ischemic stroke patients resulted in greater disability avoidance at a lower cost compared to conventional hospital care[17].

For LMICs, the most impactful and cost effective interventions may not be the most technologically

advanced acute treatments, but rather foundational public health measures. A strategic shift in global health funding and national health budgets towards primary prevention (e.g., hypertension control, lifestyle interventions) and strengthening basic, prehospital emergency care (e.g., CHW training, basic ambulance services) could yield a significantly higher return in DALYs averted and reduced societal burden. This does not negate the need for acute care but prioritizes building a robust base first, ensuring that when patients do need advanced care, the system is prepared to deliver it efficiently.

4.3. Innovative Funding Models and Sustainable Investment Strategies

Innovative funding models are urgently required to address the significant funding gap for high-cost chronic NCD treatments, including stroke, in LMICs. These models can focus on either unlocking new funding sources or efficiently deploying existing funds to patients. Strategies include leveraging strategic partnerships, multi-donor pooling, sales-linked and matched donations, and charity-funded medical partnerships. Government-initiated methods, such as compulsory medical savings accounts, lottery-based funding, sin taxes, and compassionate use models, can also enhance financial protection for patients. The emergence of technology-enabled crowd-based platforms, including patient- and partner-initiated crowdfunding and cryptocurrency-enabled platforms, offers novel avenues for resource mobilization[43],[44].

The successful implementation of these funding models hinges on local government stability, clear regulatory policies, and strong advocacy from key institutions. Programs must actively partner with local stakeholders to ensure effective execution and adoption within the specific cultural and socioeconomic context.

4.4. Policy Recommendations for Global Health Bodies and National Governments

Addressing the multifaceted challenges of stroke care in LMICs requires a concerted, multi-pronged approach from global health bodies and national governments.

At the national level, adequately funded strategies specifically for prehospital stroke care are essential[40],[52]. Strengthening overall health systems and promoting Universal Health Coverage (UHC) are critical to reducing existing disparities in access and quality of care. Global health bodies must prioritize investment in fundamental infrastructure, including improved road networks, ambulance systems, and diagnostic tools like CT scanners, and advocate for the subsidization of essential drugs such as tPA.

Workforce development is paramount. This includes training a greater number of specialized stroke professionals, as well as all levels of healthcare providers, from community health workers to EMS personnel. Policy advocacy at the global level should focus on improving stroke care through targeted infrastructure development, comprehensive workforce training, and supportive policy frameworks. It is crucial to develop locally contextualized guidelines for stroke care and rehabilitation, rather than simply implementing blanket guidelines from HICs, which often prove impractical due to resource constraints[40],[52]. Finally, improved stroke surveillance and robust data collection mechanisms are vital to inform evidence-based policy decisions and effectively evaluate the impact of interventions.

5. Conclusion: A Unified Call to Action for Equitable Stroke Care

Stroke care in LMICs represents a gauntlet of compounding delays, critical shortages, and deep-seated inequities. From the initial onset, where pervasive ignorance and geographical isolation delay symptom recognition, to prehospital gaps that strand patients, acute care crippled by missing diagnostic tools and unaffordable therapies, and rehabilitation undercut by severe resource scarcity, the system profoundly fails its most vulnerable populations. The latest global data unequivocally demonstrates that stroke's disproportionate toll in LMICs is not merely a medical crisis but a profound socioeconomic one, rooted in systemic global health disparities.

Hope for mitigating this crisis lies in a unified, multi-faceted, and context-sensitive approach. Community education initiatives, coupled with mobile health

innovations and task-shifting models, offer scalable pathways to improve early recognition and response. Strategic investment in foundational emergency services and affordable diagnostics must be prioritized. This may involve leveraging innovative funding mechanisms and strategically "leapfrogging" traditional infrastructure development where appropriate, rather than attempting to replicate expensive HIC models directly. Simultaneously, strengthening rehabilitation systems, with a deliberate focus on community-based models and formal caregiver support, is vital for achieving long-term functional recovery and ensuring economic stability for affected households.

Equity demands that stroke need not remain a death sentence or a life of profound disability in LMICs. With sustained global investment, tailored policy frameworks that recognize local realities, and a commitment to local adaptation rather than mere replication of HIC paradigms, stroke can transition from a devastating, often fatal, event to a manageable chronic condition, as it largely is in HICs. The path forward is clear – now, the world must walk it with urgency and unwavering resolve.

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